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No. 1523

BEARING STRENGTHS OF SOME ALUMINUM-ALLOY SAND CASTINGS

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Aluminum Company of America

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SUMMARY

Bearing tests were made of aluminum-alloy sand castings of 195-T4, 195-T6, 220-T4, and 356-T6 to evaluate the bearing strength of these alloys and their relation to tensile properties. Comparisons between tensile properties obtained from individually cast test bars and specimens machined from the bearing-test slabs emphasize the fact that size and form of casting may have a significant effect upon mechanical properties. The bearing-strength characteristics of these aluminum castings with respect to edge distance and ratios of specimen width to pin diameter were not significantly different from those which have been observed for the common wrought-aluminum alloys. The ratios of bearing yield to tensile yield strengths for the castings were about 20 percent higher than those for the wrought materials; the ratios of bearing ultimate to tensile ultimate strengths were about the same. Ratios of bearing to tensile strengths are proposed as a basis for the selection of allowable bearing values for the design of aluminum-alloy sand castings.

INTRODUCTION

The bearing tests described in this report are the first to be made in the Aluminum Research Laboratories on aluminum-alloy sand castings and constitute part of a general program of research covering the determination of the mechanical properties of the light-weight structural alloys of interest in aircraft design. Although bearing strengths are probably not a very important factor in the design of most aluminum-alloy sand castings, some data relating to this property are needed.

Reference 1 lists three sand-cast aluminum alloys: 195, 220, and 356. Values of ultimate bearing strength are given for the first two, for an edge distance of twice the pin diameter, but no other bearing data are given. These tests were undertaken to provide a more complete evaluation of the bearing-strength characteristics of these alloys. The following tempers were investigated: 195-T4, 195-T6, 220-T4, and 356-T6.

MATERIAL

The bearing specimens were made in the form of cast slabs, 6 by 12 by $\frac{3}{8}$ inch thick. These slabs were sawed in two and machined to provide bearing-test specimens $2\frac{1}{4}$ inches wide by 12 inches long in thicknesses of both 1/4 and 1/8 inch. Material was machined from both faces of the castings. Individually cast tension test bars of $\frac{1}{2}$-inch diameter were provided with each lot of bearing specimens. All the slabs supplied for test were X-rayed and found to be typically sound and free from defects.

PROCEDURE

Figure 1 shows the manner in which the bearing tests were made. The $\frac{1}{4}$-inch-thick specimens were loaded on a $\frac{1}{2}$-inch-diameter steel pin, whereas those having a thickness of $\frac{1}{8}$ inch were loaded on a $\frac{1}{4}$-inch-diameter pin. Edge distances, measured in the direction of stressing from the center of the pin hole to the edge of the specimen, ranged from 1.5 to 4 times the diameter of the pin. Tests were made in triplicate in most cases.

Hole deformations, from which values of bearing yield strength were determined, were obtained by measuring the relative movement of the pin and the specimen by means of a filar micrometer microscope, which could be read directly to 0.01 millimeter. The projecting portion of the pin on the microscope side was flattened slightly on the under side to provide a shoulder on which the reference mark for pin movement was located; a small scratch on the specimen under the pin provided the reference for specimen movement.

In addition to tensile tests made on the standard $\frac{1}{2}$-inch-diameter individually cast test bars, tensile specimens were also machined from the bearing-test slabs. Properties from the latter were desirable to provide a direct correlation between bearing and tensile strengths. Compression and shear specimens were also machined from the cast slabs. Table I gives the dimensions of these specimens.

RESULTS AND DISCUSSION

Table I summarizes the results of all the tensile, compressive, and shear tests made in this laboratory and includes specified minimum as well as typical properties for purposes of comparison. Mechanical property data reported by the foundry are also included.

The tensile strengths obtained in this laboratory from the $\frac{1}{2}$-inch-diameter test bars ranged from 18 to 32 percent higher than the minimum specified values for the castings and from 7 to 20 percent higher than those considered as typical. The greatest differences were observed for the 195-T4 specimens which were susceptible to natural aging at room temperature. The tensile properties obtained in tests made at the foundry, approximately 1 week after heat treatment and 3 months prior to the tests made at the laboratory, show the extent of the natural aging produced. Some natural aging also seemed to be indicated for the 195-T6 test bars. The two sets of data for the 356-T6 and 220-T4 specimens, however, were in very close agreement.

The tensile strengths obtained from the specimens machined from the cast slabs ranged from 16 to 29 percent less than the values obtained from the corresponding $\frac{1}{2}$-inch-diameter test bars, the greatest difference being observed for the 220-T4. All values were, nevertheless, above the minimum allowable for test specimens of this type. The tensile yield strengths obtained for the 195-T4 and 195-T6 castings were several thousand pounds per square inch higher than those obtained for the corresponding $\frac{1}{2}$-inch-diameter test bars; this would again seem to indicate additional natural aging, since the yield strengths observed for the 356-T6 and 220-T4 samples were essentially the same for the two types of specimen. Elongation values obtained from the slabs were in all cases less than those obtained from the $\frac{1}{2}$-inch-diameter test bars, although all the former were above the minimum that would be permitted in tests of specimens machined from castings.

The compressive yield strengths obtained from specimens machined from the slabs were consistently higher than the corresponding tensile yield values, the maximum difference for the 195-T4 being 11 percent. The ultimate shear strengths, which are generally considered to range from about 70 to 85 percent of the tensile strengths, exceeded the latter in two of the four cases. The significant conclusion to be drawn from these comparisons is that relations between tensile, compressive, and shear properties commonly based on tests of separately cast test bars may not always be representative of larger castings.

Table II and figures 2 to 10 give the results of the bearing tests. Values of bearing yield strength were selected from the bearing stress-hole elongation curves as the stresses corresponding to an offset of 2 percent of the pin diameter from the initial straight-line portion of the curves. Ratios of the average bearing to tensile properties, the latter obtained from tests of specimens machined from the cast slabs, are given in table III.

The effect of edge distance upon bearing strengths and the general behavior of the castings in bearing was not significantly different from that observed previously for a number of wrought-aluminum alloys (reference 2). The bearing yield strengths were not sensitive to the differences in ratio of specimen width to pin diameter investigated and were not appreciably higher for edge distances of 4D (4 × pin diameter) than for edge distances of 2D; this was consistent with the conception of bearing yield strength as a strictly local yielding phenomenon. Although the ratios of bearing yield strength to tensile yield strength for any one edge distance were approximately the same for all alloys and tempers, the magnitude of these ratios was somewhat higher than that generally obtained for wrought aluminum. The ratios for the castings averaged about 1.7 for an edge distance of 1.5D and 2.0 for an edge distance of 2D, as compared with corresponding ratios of 1.4 and 1.6 for the wrought alloys.

Ratios of bearing ultimate strength to tensile ultimate strength for the castings tested on a $\frac{1}{2}$-inch-diameter pin were of the same order of magnitude as that observed for wrought-aluminum alloys, particularly those of the medium-strength class. Ratios for the tests on a $\frac{1}{4}$-inch-diameter pin were consistently higher, as expected. For both sizes of pin and for edge distances of 1.5D and 2D, the ratios were highest for the 220-T4 castings which exhibited the highest tensile elongation values.

CONCLUSIONS

The results of bearing tests of aluminum-alloy sand castings of 195-T4, 195-T6, 220-T4, and 356-T6 are believed to warrant the following conclusions regarding bearing strengths and their relation to tensile properties:

1. The tensile properties of the 195-T6, 356-T6, and 220-T4 individually cast test bars representing the bearing-test slabs were reasonably close to published typical values. These materials were considered suitable, therefore, for an investigation of bearing-strength characteristics and a determination of general relationships between bearing and tensile properties.

2. The 195-T4 castings (heat-treated, but not artificially aged) aged naturally in a period of approximately 3 months to tensile strengths comparable with those obtained for 195-T6. The instability of the T4 temper raises a question as to the significance of minimum specified strength values for this temper for structural design.

3. Comparisons between tensile properties obtained from individually cast test bars and specimens machined from the bearing-test slabs emphasize the well-known fact that size and form of casting may have a significant effect upon mechanical properties.

4. The bearing-strength characteristics of these aluminum castings with respect to edge distance and ratios of specimen width to pin diameter were not significantly different from those which have been observed for the common wrought-aluminum alloys. The ratios of bearing yield to tensile yield strengths for the castings were about 20 percent higher than those for the wrought materials; the ratios of bearing ultimate to tensile ultimate strengths were about the same.

5. The following ratios of bearing to tensile strengths are proposed as a basis for the selection of allowable bearing values for the design of aluminum-alloy sand castings.

Ratio	Edge distances	
	1.5 × pin diam.	2 × pin diam. or greater
$\frac{\text{Bearing yield}}{\text{Tensile yield}}$	1.7	2.0
$\frac{\text{Bearing ultimate}}{\text{Tensile ultimate}}$	1.6	2.1

Aluminum Research Laboratories
Aluminum Company of America
New Kensington, Pa., November 6, 1946

REFERENCES

1. Anon.: Strength of Aircraft Elements ANC-5, Amendment No. 1, Oct. 22, 1943.

2. Moore, R. L., and Wescoat, C.: Bearing Strengths of Some Wrought-Aluminum Alloys. NACA TN No. 901, 1943.

TABLE I

SUMMARY OF MECHANICAL PROPERTIES OF SOME

ALUMINUM-ALLOY SAND CASTINGS

Alloy and temper	Sample	Tensile properties of $\frac{1}{2}$-in.-diameter test bars[1]: Tensile ultimate strength (psi)	Yield strength (Offset = 0.2 percent) (psi)	Elongation in 2 in. (percent)	Date of test	Where tested	Properties of 3/8- by $2\frac{1}{4}$- by 12-in. cast slabs[2]: Tensile ultimate strength (psi)	Tensile yield strength (Offset = 0.2 percent) (psi)	Elongation in 2 in. (percent)	Date of tensile tests	Compressive yield strength (Offset = 0.2 percent) (psi)	Ultimate shear strength (psi)	Ratio: $\frac{\text{Shear strength}}{\text{Tensile strength}}$
195-T4	C1678-A	38,400	26,000	5.8	5-22-45	Laboratory	31,400	28,100	2.0	9-19-46	31,200	32,400	1.03
		36,200	18,800	9.1	2-26-45	Foundry	------	------	---	------	------	------	----
Specified	minimum[3]	29,000	------	6.0	------	------	22,000	------	1.5	------	------	------	----
Typical		32,000	16,000	8.5	------	------	------	------	---	------	------	------	----
195-T6	C1678-B	39,900	25,800	5.2	5-22-45	Laboratory	32,600	28,800	2.0	9-19-46	31,000	34,400	1.05
		38,100	22,100	6.8	2-26-45	Foundry	------	------	---	------	------	------	----
Specified	minimum	32,000	------	3.0	------	------	24,000	------	.8	------	------	------	----
Typical		36,000	24,000	5.0	------	------	------	------	---	------	------	------	----
356-T6	C1679	35,400	27,200	2.6	5-22-45	Laboratory	29,800	26,600	2.0	9-19-46	28,000	25,900	.87
		35,400	27,200	3.2	------	Foundry	------	------	---	------	------	------	----
Specified	minimum	30,000	------	3.0	------	------	22,000	------	.8	------	------	------	----
Typical		33,000	24,000	4.0	------	------	------	------	---	------	------	------	----
220-T4	C1882	49,700	27,000	17.6	6-9-45	Laboratory	35,400	27,600	5.0	9-19-46	29,200	35,000	.99
		50,700	26,100	19.7	------	Foundry	------	------	---	------	------	------	----
Specified	minimum	42,000	------	12.0	------	------	32,000	------	3.0	------	------	------	----
Typical		46,000	25,000	14.0	------	------	------	------	---	------	------	------	----

[1]Individually cast specimens tested without machining off surface. See figure 1, Tentative Specifications for Aluminum-Base Alloy Sand Castings (B26-44T), 1944 Book of A.S.T.M. Standards, Part I.
Values for both laboratory and foundry tests are average of six tests.

[2]Specimens machined from central portion of cast slabs. See Army-Navy-Aeronautics Specification AN-A-23.
Tensile specimens, standard $\frac{1}{2}$-in.-wide sheet type, $\frac{1}{4}$ in. thick (2 tests).
Compression specimens, standard sheet type, $1/4 \times 5/8 \times 2.63$ in. (2 tests).
Shear specimens, $\frac{3}{16}$-in. diam. $\times$ 3 in. (4 tests).

[3]Specified minimum values for $\frac{1}{2}$-in.-diam. test bars taken from Alcoa Aluminum and Its Alloys, table 13. Minimum values of tensile strength and elongation for castings not to be less than 75 percent and 25 percent, respectively, of properties specified for $\frac{1}{2}$-in.-diam. test bars. See Specification AN-A-23.

TABLE II

BEARING STRENGTHS OF SOME ALUMINUM-ALLOY SAND CASTINGS

Alloy and temper	Test	Bearing strengths for edge distances of - (psi)								
		1.5 × pin diameter			2 × pin diameter			4 × pin diameter		
		Ultimate	Yield (1)	Type of failure (2)	Ultimate	Yield (1)	Type of failure	Ultimate	Yield (1)	Type of failure
Bearing tests of $\frac{1}{2}$-in.-diameter steel pin in $\frac{1}{4}$-in.-thick by $2\frac{1}{4}$-in.-wide castings										
195-T4	1	51,800	48,800	TS	69,100	56,400	TS	91,100	59,200	T
	2	49,800	48,000	TS	69,800	59,600	TS	96,000	60,800	T
	3	51,400	49,200	TS	68,000	56,000	TS	95,900	59,200	T
	Av.	51,000	48,700		69,000	57,300		94,300	59,700	
195-T6	1	53,400	51,000	TS	74,300	61,900	TS	99,600	61,900	T
	2	52,000	50,800	TS	72,000	61,000	TS	98,600	62,500	T
	3	51,100	51,600	TS	70,800	60,900	TS	97,600	65,000	T
	Av.	52,200	51,100		72,300	61,300		98,600	63,100	
356-T6	1	47,500	45,500	TS	62,000	55,400	TS	71,000	56,300	T
	2	47,900	47,500	TS	63,600	53,500	TS	83,700	59,200	T
	3	47,500	46,500	TS	63,700	55,600	TS	79,900	57,400	T
	Av.	47,600	46,500		63,100	54,800		78,200	57,600	
220-T4	1	68,700	50,400	T	84,600	56,500	T	106,000	57,000	T
	2	71,400	51,000	T	87,600	58,000	T	100,600	61,000	T
	3	68,100	49,500	T	82,100	55,000	T	100,600	58,000	T
		69,400	50,300		84,800	56,500		102,400	58,700	
Bearing tests on $\frac{1}{4}$-in.-diameter steel pin in $\frac{1}{8}$-in.-thick by $2\frac{1}{4}$-in.-wide castings										
195-T4	1	57,100	49,300	TS	------	------	--	137,100	63,900	TS
	2	59,000	48,000	TS	80,500	61,000	TS	134,600	61,000	TS
	3	61,500	49,000	TS	78,200	59,500	TS	125,200	64,000	TS
	4	64,200	53,000	TS	------	------	--	-------	------	--
	Av.	60,500	49,800		79,300	60,200		132,300	63,000	
195-T6	1	59,800	50,000	TS	82,400	60,000	TS	129,400	60,000	TS
	2	59,500	50,900	TS	82,400	61,000	TS	131,000	63,500	TS
	3	57,700	53,300	S	81,600	63,000	TS	134,600	67,500	TS
	Av.	59,000	51,400		82,100	61,300		131,700	63,700	
356-T6	1	52,300	52,000	TS	62,600	56,500	TS	102,600	58,500	TS
	2	48,400	48,000	TS	63,700	53,500	TS	109,300	64,000	T
	3	------	------	--	62,300	54,500	TS	-------	------	--
	Av.	50,300	50,300		62,900	54,800		106,000	61,300	
220-T4	1	82,200	50,900	S	99,500	57,900	TS	141,300	59,000	T
	2	85,400	49,000	TS	104,700	57,000	TS	155,600	60,000	T
	3	83,100	48,500	S	94,300	48,500	TS	150,300	59,900	T
	Av.	83,600	49,500		99,500	54,500		149,000	59,600	

[1] Stress corresponding to offset of 2 percent of pin diameter from initial straight-line portion of hole-elongation curves.

[2] Types of bearing failure: T, tension on section through hole; S, shear above pin; TS, combination of tension and shear.

TABLE III

RATIOS OF AVERAGE BEARING TO TENSILE STRENGTHS FOR SOME ALUMINUM-ALLOY SAND CASTINGS

[Ratios based on tensile properties obtained from bearing-test slabs. BS, bearing ultimate strength; BYS, bearing yield strength; TS, tensile ultimate strength; TYS, tensile yield strength.]

Alloy and temper	Ratios for edge distances of -					
	1.5 × pin diameter		2.0 × pin diameter		4.0 × pin diameter	
	$\frac{BS}{TS}$	$\frac{BYS}{TYS}$	$\frac{BS}{TS}$	$\frac{BYS}{TYS}$	$\frac{BS}{TS}$	$\frac{BYS}{TYS}$
Bearing tests on $\frac{1}{2}$-in.-diameter steel pin in $\frac{1}{4}$-in.-thick by $2\frac{1}{4}$-in.-wide castings						
195-T4	1.62	1.73	2.20	2.04	3.00	2.12
195-T6	1.60	1.77	2.21	2.13	3.02	2.19
356-T6	1.60	1.75	2.12	2.06	2.62	2.17
220-T4	1.96	1.82	2.39	2.05	2.89	2.13
Bearing tests on $\frac{1}{4}$-in.-diameter steel pin in $\frac{1}{8}$-in.-thick by $2\frac{1}{4}$-in.-wide castings						
195-T4	1.92	1.77	2.52	2.14	4.21	2.24
195-T6	1.81	1.77	2.52	2.13	4.03	2.21
356-T6	1.69	1.89	2.11	2.06	3.56	2.30
220-T4	2.36	1.79	2.81	1.97	4.21	2.16

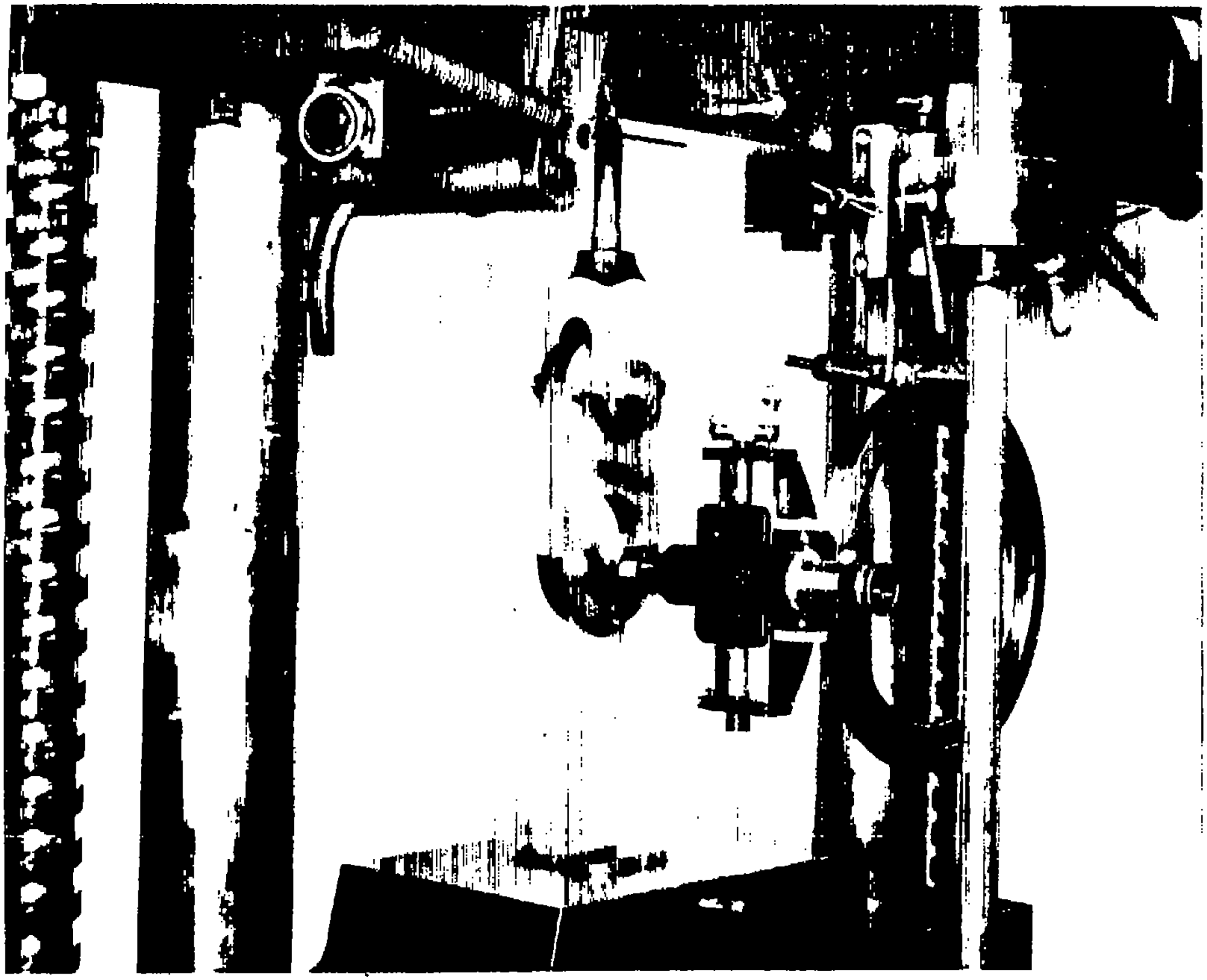

Figure 1.- Arrangement for bearing tests.

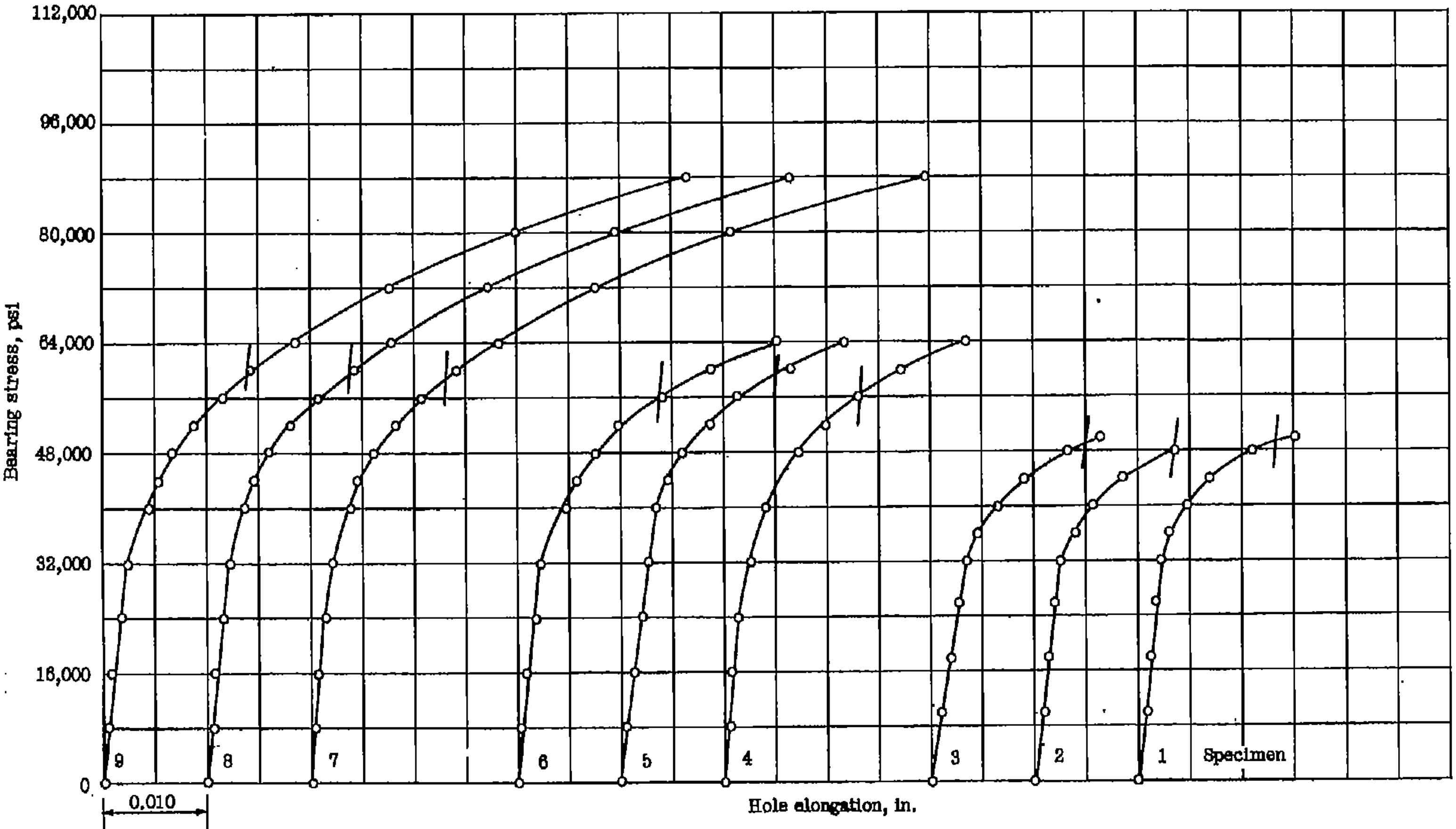

Figure 2.- Bearing stress-hole elongation curves for 195-T4 aluminum-alloy castings. Specimen thickness, 1/4 inch; specimen width, 2-1/4 inches; pin diameter D, 1/2 inch; edge distance, 1.5D for specimens 1, 2, and 3; edge distance, 2D for specimens 4, 5, and 6; edge distance, 4D for specimens 7, 8, and 9; bearing yield corresponds to offset of 0.02D.

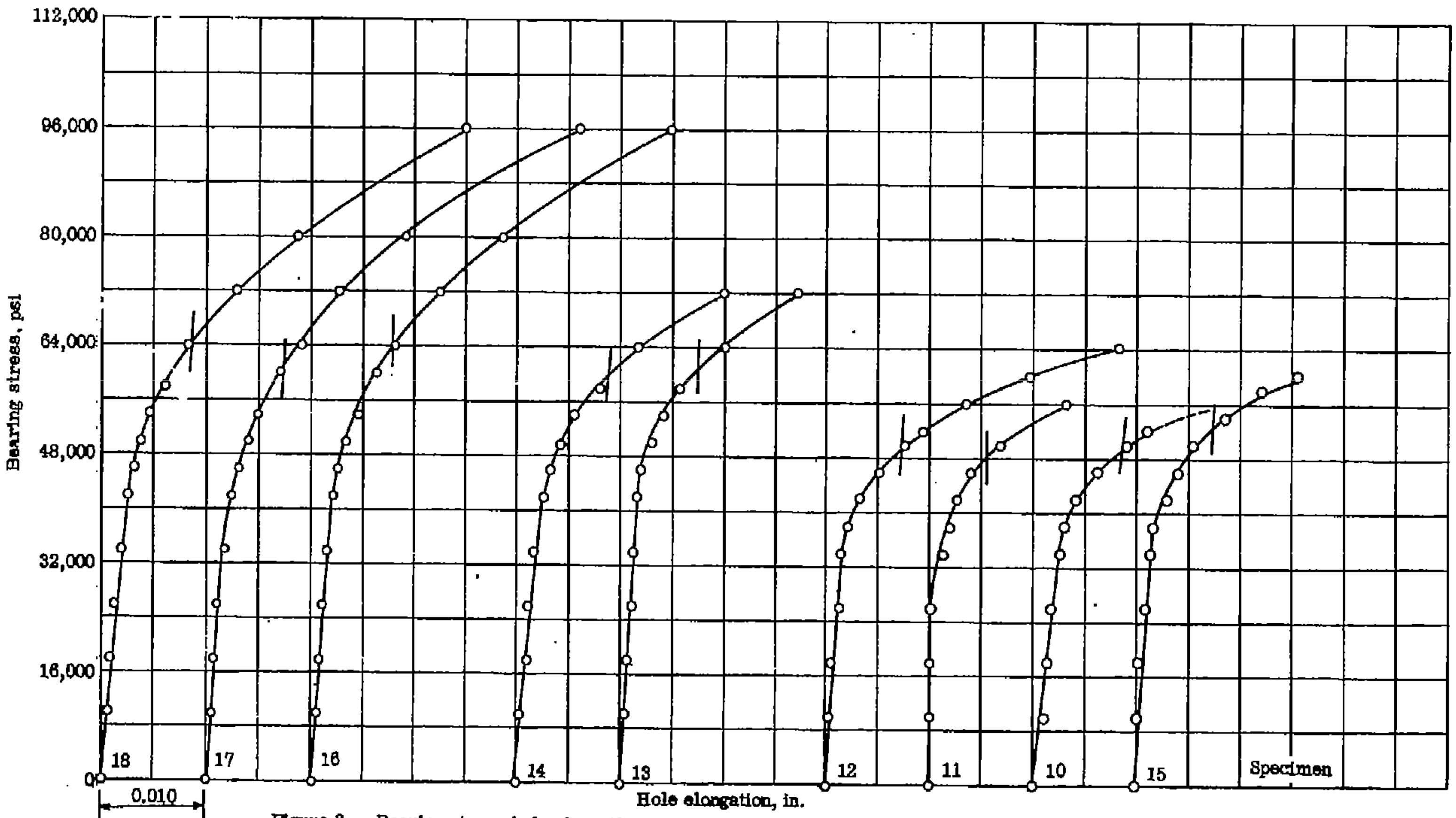

Figure 3.- Bearing stress-hole elongation curves for 195-T4 aluminum-alloy castings. Specimen thickness, 1/8 inch; specimen width, 2-1/4 inches; pin diameter D, 1/4 inch; edge distance, 1.5D for specimens 10, 11, 12, and 15; edge distance, 2D for specimens 13 and 14; edge distance, 4D for specimens 16, 17, and 18; bearing yield corresponds to offset of 0.02D.

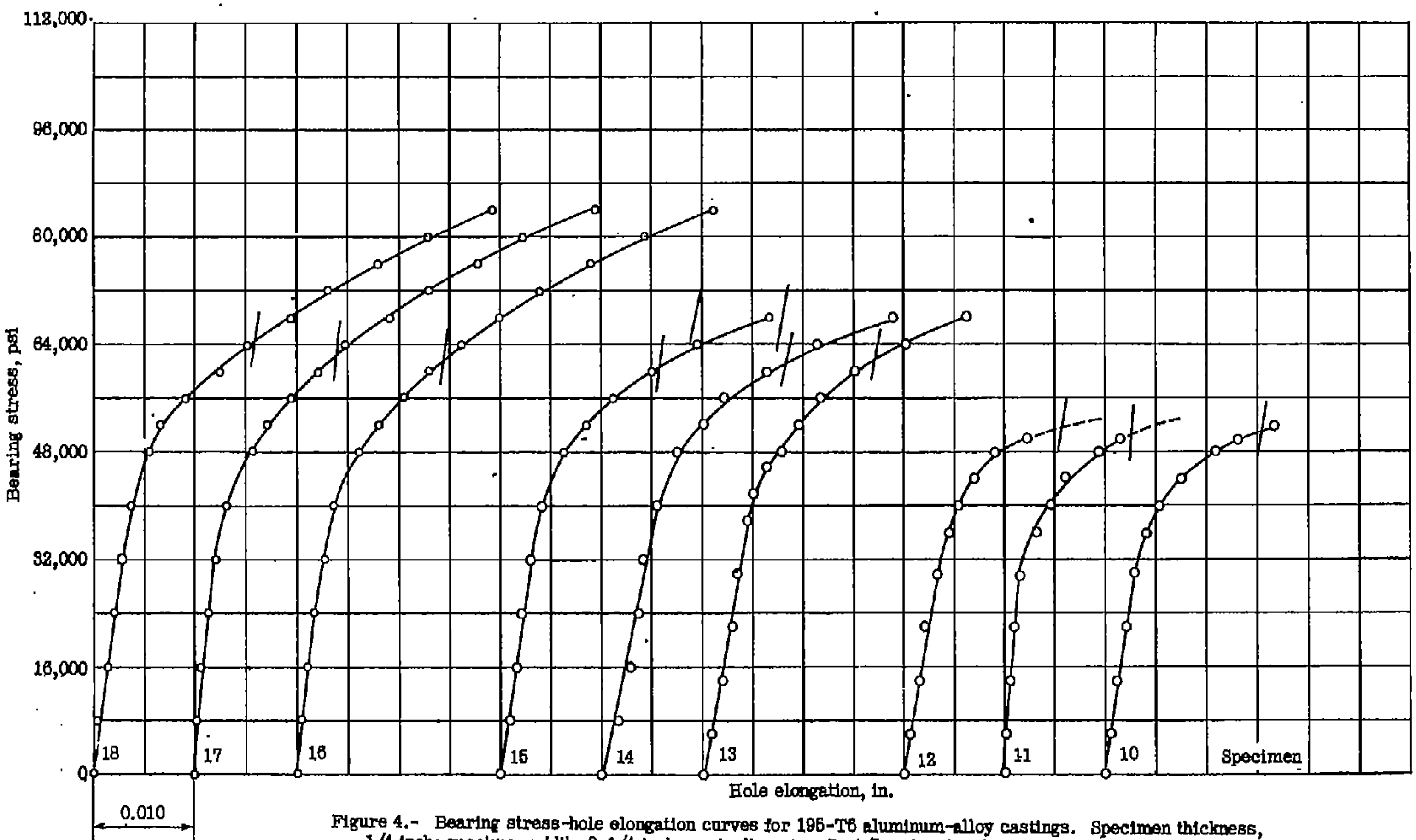

Figure 4.- Bearing stress-hole elongation curves for 195-T6 aluminum-alloy castings. Specimen thickness, 1/4 inch; specimen width, 2-1/4 inches; pin diameter D, 1/2 inch; edge distance, 1.5D for specimens 10, 11, and 12; edge distance, 2D for specimens 13, 14, and 15; edge distance, 4D for specimens 16, 17, and 18; bearing yield corresponds to offset of 0.02D.

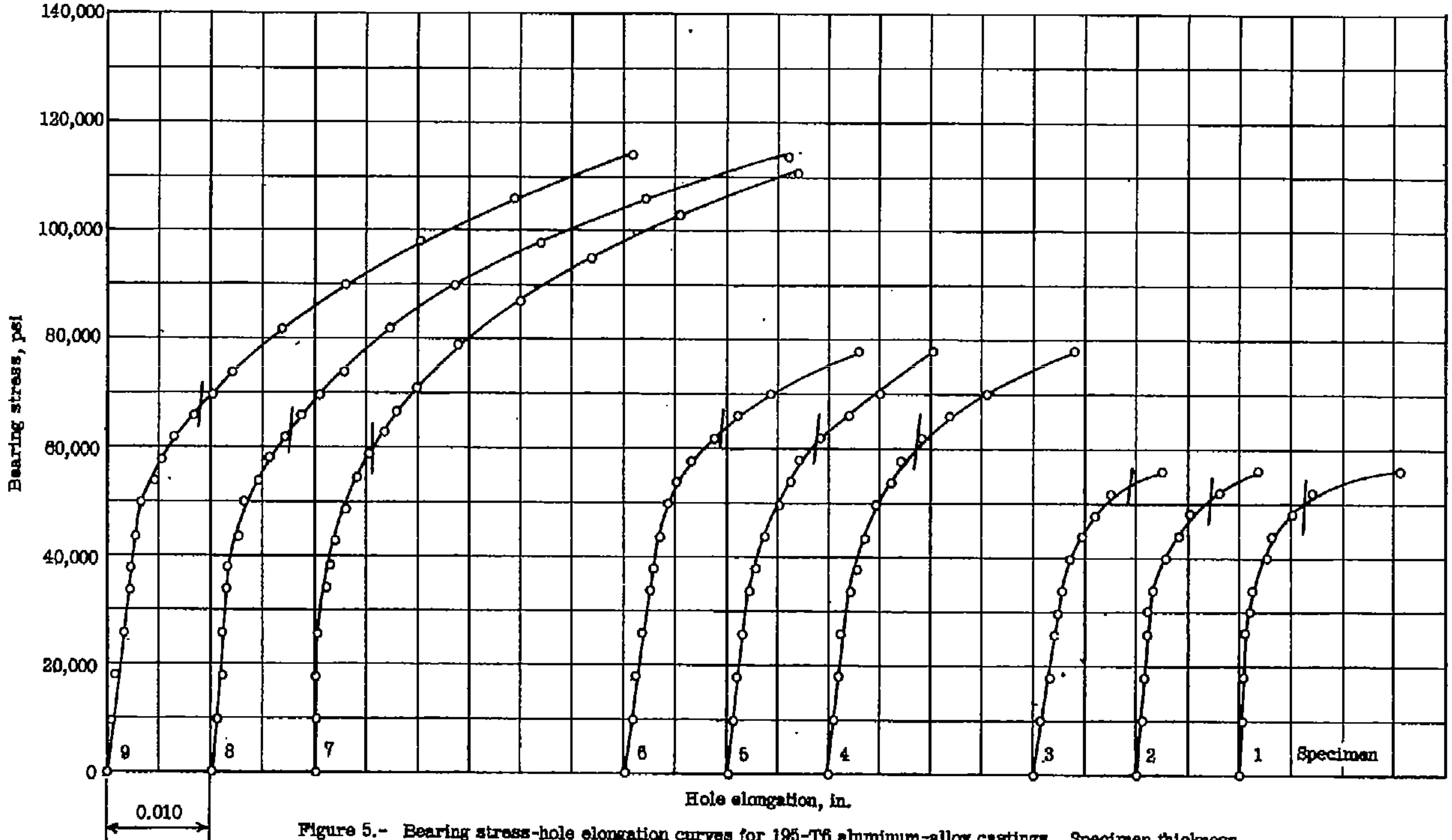

Figure 5.- Bearing stress-hole elongation curves for 195-T6 aluminum-alloy castings. Specimen thickness, 1/8 inch; specimen width, 2-1/4 inches; pin diameter D, 1/4 inch; edge distance, 1.5D for specimens 1, 2, and 3; edge distance, 2D for specimens 4, 5, and 6; edge distance, 4D for specimens 7, 8, and 9; bearing yield corresponds to offset of 0.02D.

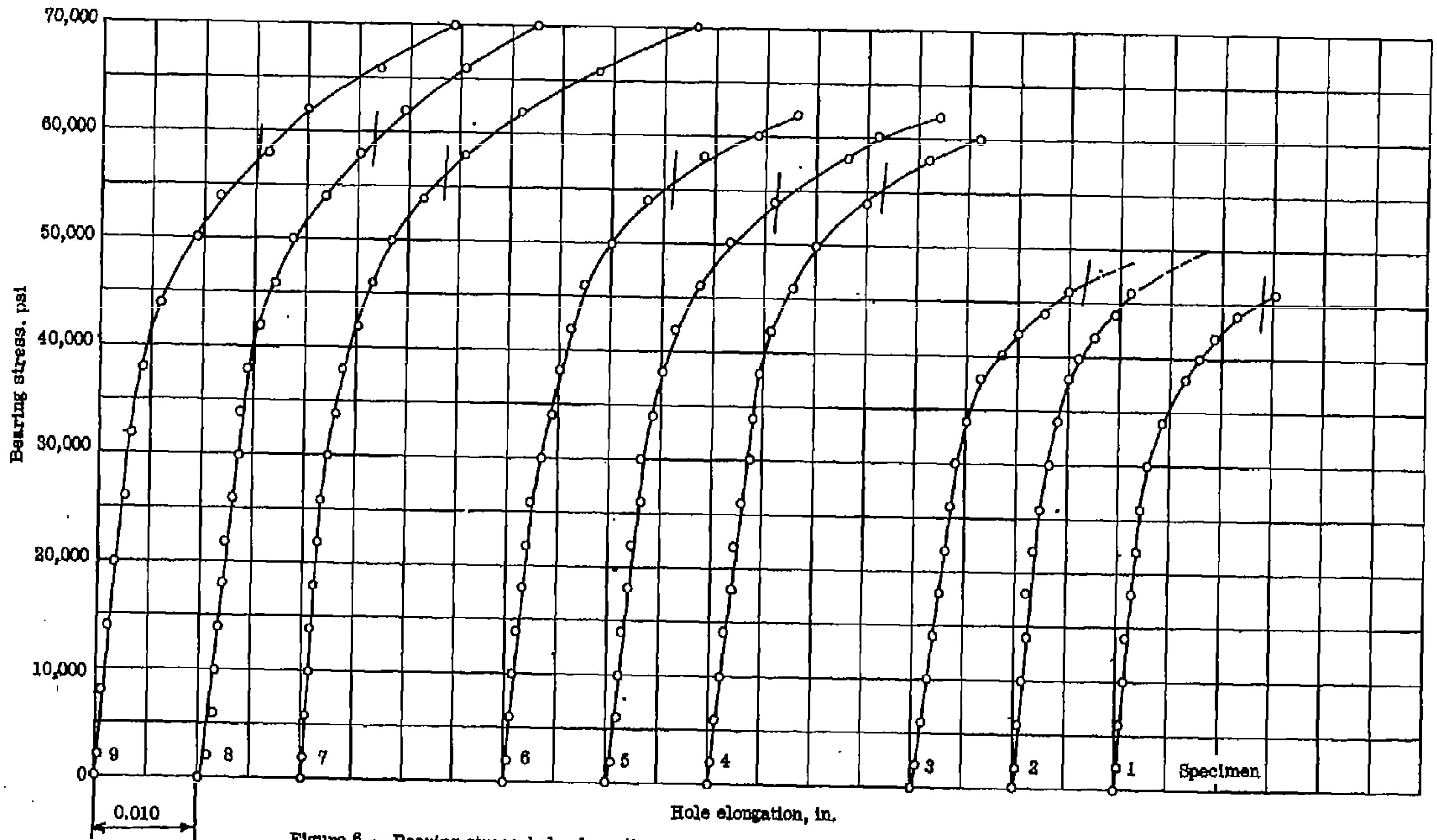

Figure 6.- Bearing stress-hole elongation curves for 356-T6 aluminum-alloy castings. Specimen thickness, 1/4 inch; specimen width, 2-1/4 inches; pin diameter D, 1/2 inch; edge distance, 1.5D for specimens 1, 2, and 3; edge distance, 2D for specimens 4, 5, and 6; edge distance, 4D for specimens 7, 8, and 9; bearing yield corresponds to offset of 0.02D.

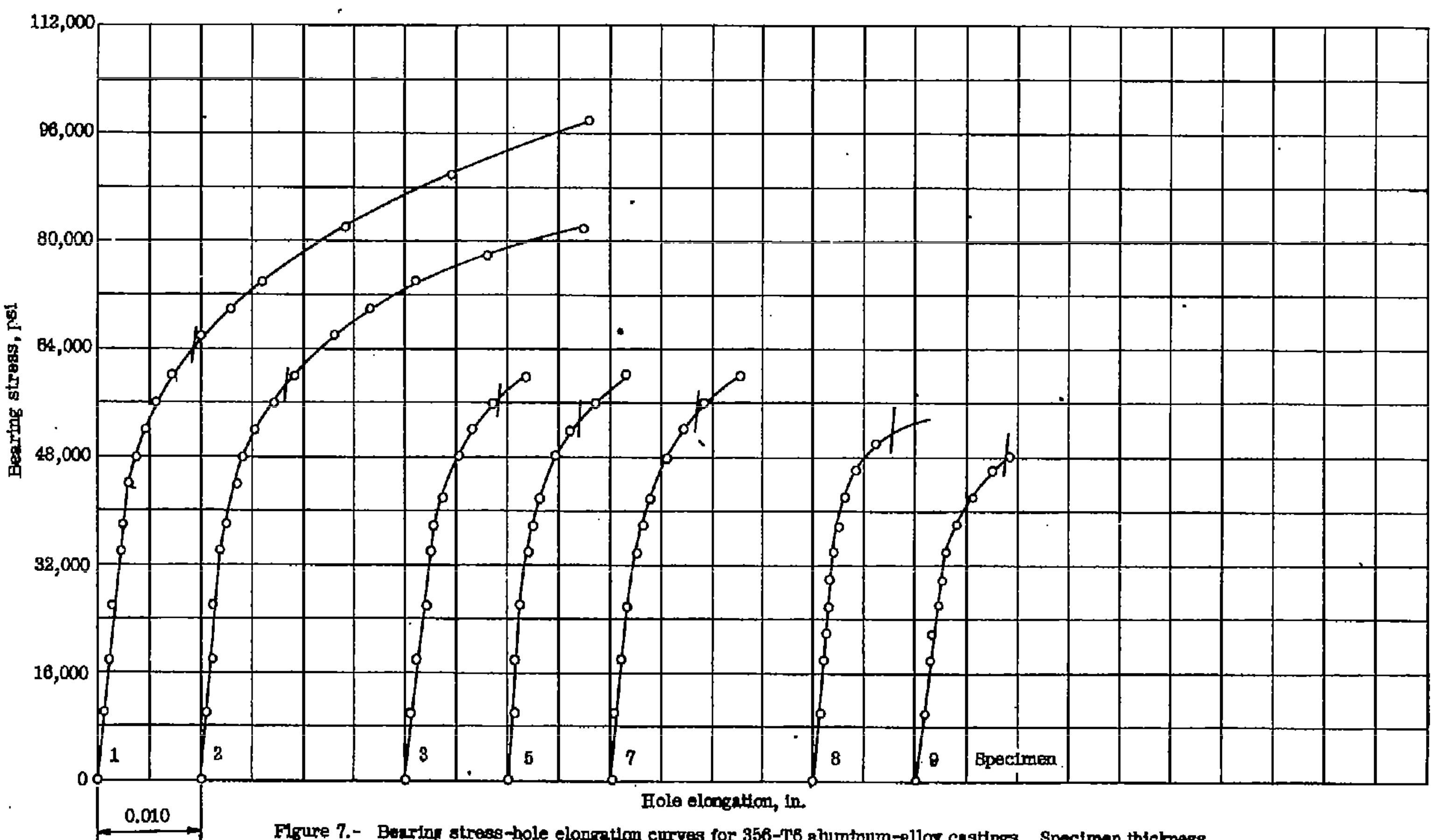

Figure 7.- Bearing stress-hole elongation curves for 356-T6 aluminum-alloy castings. Specimen thickness, 1/8 inch; specimen width, 2-1/4 inches; pin diameter D, 1/4 inch; edge distance, 1.5D for specimens 8 and 9; edge distance, 2D for specimens 3, 5, and 7; edge distance, 4D for specimens 1 and 2; bearing yield corresponds to offset of 0.02D.

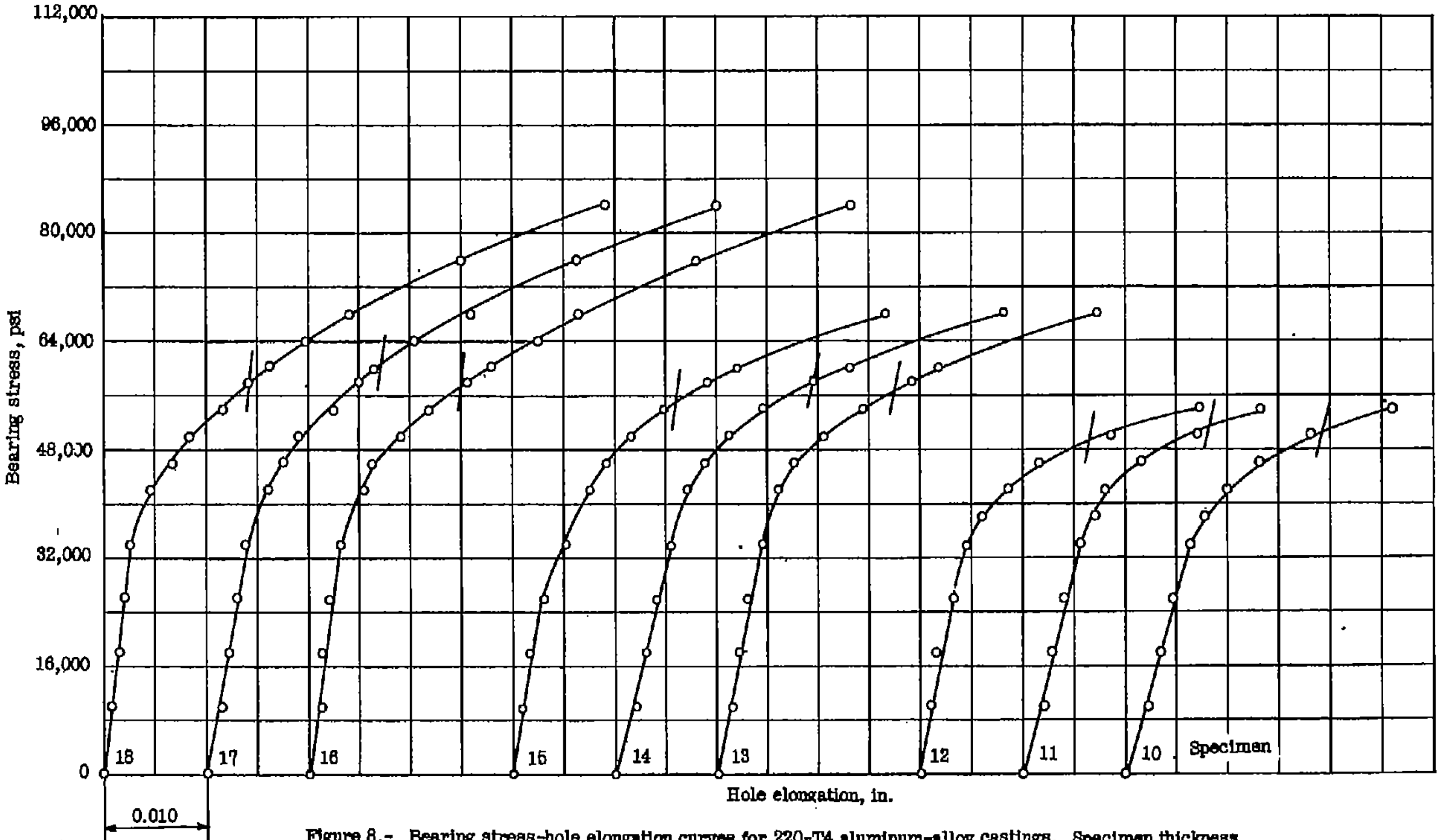

Figure 8.- Bearing stress-hole elongation curves for 220-T4 aluminum-alloy castings. Specimen thickness, 1/4 inch; specimen width, 2-1/4 inches; pin diameter D, 1/2 inch; edge distance, 1.5D for specimens 10, 11, and 12; edge distance, 2D for specimens 13, 14, and 15; edge distance, 4D for specimens 16, 17, and 18; bearing yield corresponds to offset of 0.02D.

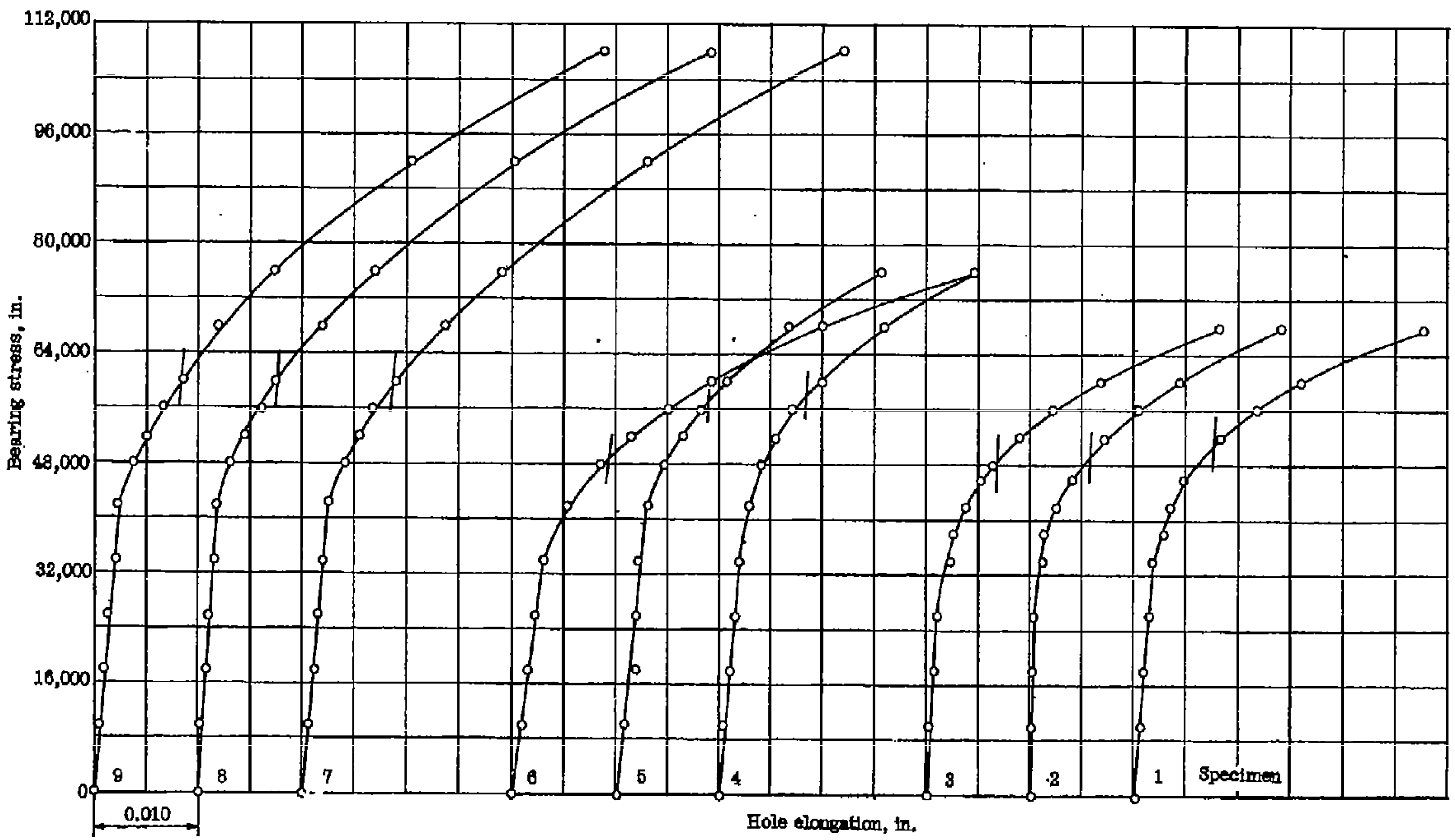

Figure 9.- Bearing stress-hole elongation curves for 220-T4 aluminum-alloy castings. Specimen thickness, 1/8 inch; specimen width, 2-1/4 inches; pin diameter D, 1/4 inch; edge distance, 1.5D for specimens 1, 2, and 3; edge distance, 2D for specimens 4, 5, and 6; edge distance, 4D for specimens 7, 8, and 9; bearing yield corresponds to offset of 0.02D.

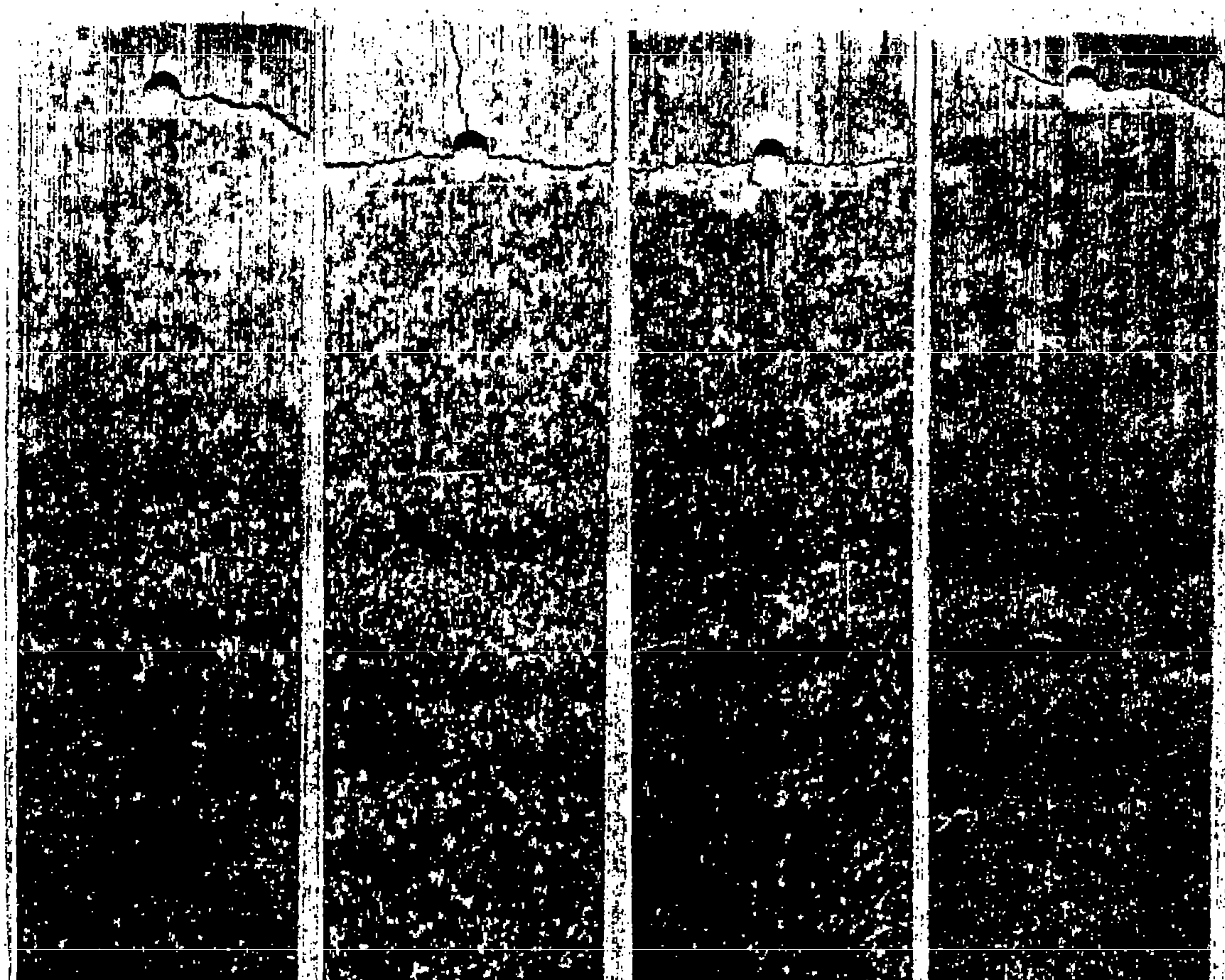

Figure 10.- Bearing failures in aluminum-alloy sand castings.